Dynamics of Coastally Trapped Disturbances Deduced from MM5 Simulations

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LONG TERM GOALS:

We wish to advance the understanding of the interaction of a large-scale flow with complex terrain in the presence of a strongly stratified marine atmospheric boundary layer.

OBJECTIVES:

We wish to carry out a detailed diagnosis of coastally trapped disturbances (CTD's) along the California coast, to document and understand dynamical mechanisms responsible for generating and maintaining such disturbances.

APPROACH:

Because of limitations in observations offshore from and along the coastline, progress in understanding mesoscale,coastal phenomena is highly dependent on diagnostic studies performed with the aid of numerical simulations. Herein, we concentrate on simulations of observed events using a nonhydrostatic mesoscale model, capable of capturing the response of coastal flows to complex orography. Upon obtaining satisfactory simulations, the internal dynamical consistency of the model can be exploited to understand the chain of events that leads to a mesoscale vortex and coastal surge.

The numerical model used is the PSU/NCAR mesoscale model (MM5, Grell et al., 1994). The model is nonhydrostatic and employs grid nesting to achieve locally high resolution. Simulation of coastally trapped disturbances requires at once the proper treatment of synoptic scale motion, along with adequate representation of local terrain effects coupled with the shallow marine boundary layer. These demands require local high resolution, but also long-time integrations to cover the life cycle of the coastal disturbances, which may be one or more days. Therefore, predictability of not only the small scale, but also the large scale becomes questionable. For the purposes of creating a

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numerical simulation which best represents the real atmosphere and therefore enhances our understanding of the real processes involved, large-scale data are continually inserted into the model in an effort to supply correct boundary conditions for the high resolution mesh necessary to capture the coastally trapped disturbance itself.

WORK COMPLETED:

During FY'98, we performed extensive diagnostics on our simulation of the Catalina Eddy event of 26-30 June, 1988 and have completed an initial draft of a manuscript describing our results. The MM5 was run first in a two-domain configuration with a coarse mesh of 60 km resolution and a fine mesh of 20 km resolution, covering a 72 hour period from 1200 UTC 27 to 1200 UTC 30 June. During this period, all available conventional data were inserted continually into the model in an effort to minimize drift of the large-scale flow away from reality. The resulting 20 km simulation then provided initial and boundary conditions for a 6.67 resolution simulation, covering the same 72 hour period. The simulation utilized 45 layers in the vertical, with a spacing averaging about 100 m over the lowest 2 km AGL, increasing to about 1 km near the top of the model (100 mb). Our diagnostics included analysis of the momentum and vorticity budgets within MM5, trajectory analysis to describe the airflow relative to the eddy and sensitivity experiments.

The momentum budget involved a time averaging of the individual terms in the momentum equation, with emphasis on the Coriolis, Pressure gradient and frictional forces. The terms were computed at each model time step and averaged over an hour of integration. This smoothed out high-frequency variations to give a more representative picture of the accelerations. Attempts to partition the substantial derivative of momentum components were not illuminating due to large, canceling terms near the steep slopes.

Trajectories were computed from a uniformly space set of parcels which resided near the vortex at the surface. Back trajectories were integrated for 12 hours, using model output at 15-minute intervals (further interpolated linearly to 5-minute intervals). This temporal resolution was felt the minimum necessary to yield consistent trajectories on the 6.7 km domain. Derived variables such as potential temperature and water vapor mixing ratio were computed along the parcel paths.

The principal sensitivity experiment was one in which the diurnal cycle was removed. We varied the start time of the forecast, either 1200 UTC 29 June (24 hours before the mature eddy was realized) or 0000 UTC 30 June. The former was designed to capture evolution when the flow impinging on the mountains north of the California bight region was relatively weak and stably stratified. The latter simulation included a strong coastal northerly jet at low-levels, the nearly geostrophic response to the strong west-east thermal gradient which develops in the afternoon. Other sensitivity experiments tested the importance of when the innermost domain was initialized, and whether changes to MM5 (which is updated on a nearly bi-monthly basis) during the course of the work might have altered results. These last two simulations did not produce results significantly different from the control simulation.

RESULTS:

We documented two scales of response to flow over/around the San Rafael and Santa Ynez Mountains. First, there is the mountain wave, on a scale of the mountain half width (10-20 km) (Fig. 1). Second there is a well-defined mountain wake and lee-side stagnation zone and the eddy itself. The eddy appears to be akin to a start-up vortex, a transient cyclonic circulation resulting from an impulsive acceleration of flow over the mountains. In the present Case, the acceleration of the upstream flow is brought about by the diurnal cycle, in which the daytime land-sea contrast results in an evening enhancement in the low-level northerlies and consequently an enhanced orographic response.

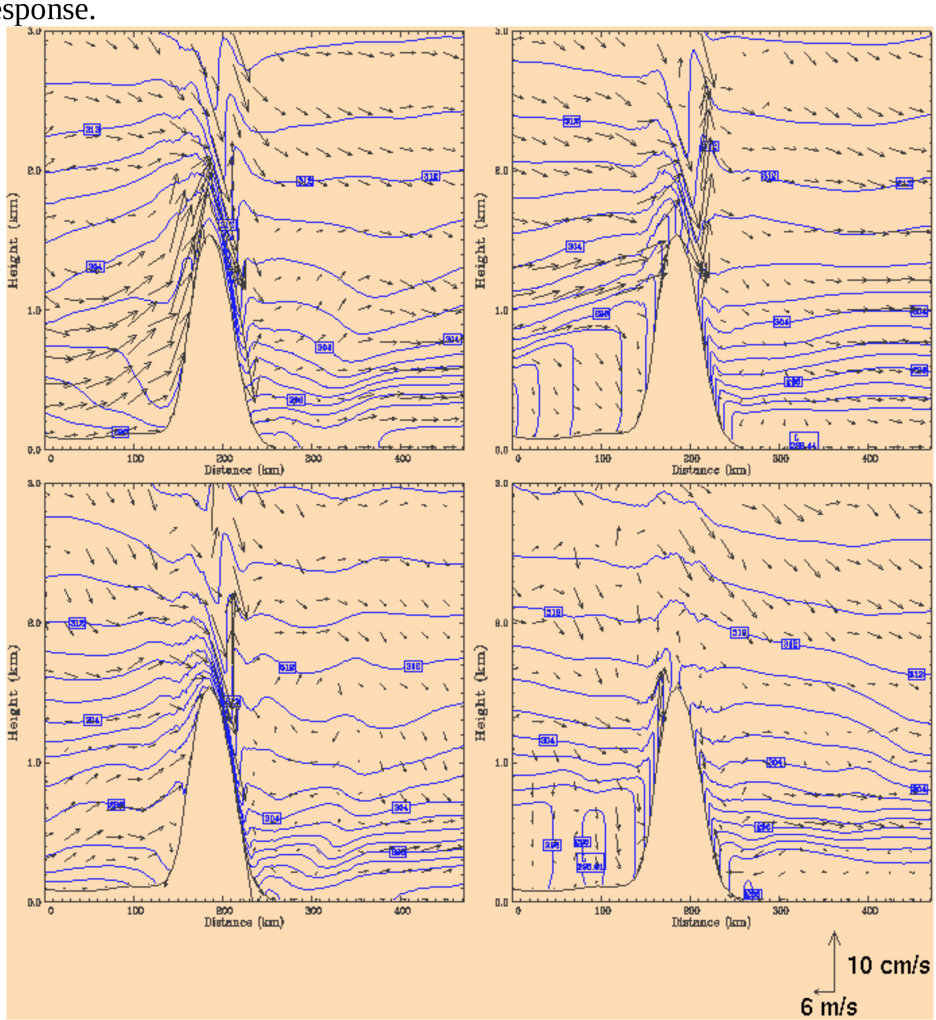

Figure 1. North-south cross sections (see Fig. 2 for location) showing horizontal and vertical motion in the plane of the section, and potential temperature (contour interval 2 K); (a) 0600 UTC 28 June (18 hours); (b) 1800 UTC 28 June (30 hours); (c) 0600 UTC 30 June (66 hours) and (d) 1800 UTC 30 June (78 hours). Vector scales are at lower right.

The synoptic-scale evolution can be thought of as the trigger for the Catalina Eddy event. This thinking pervades the study by Mass and Albright (1989). In the present case, it appears that the weakening of the synoptic-scale flow on 30 June is a key for allowing the eddy to persist in the bight region. Strong cyclonic vorticity is generated on previous days, but the incoming flow then is strong enough to advect it away from the bight region on a time scale of only a few hours.

In previous studies, strong emphasis has been placed on the trapping of flow by the coastal mountains, resulting in northward acceleration, as the defining act the formation of a mature eddy. (Mass and Albright 1989, Clark 1993). There is some evidence that a few trajectories were shunted northward by the mountains, but, overall, the southerlies were not well-confined to the coast in the model. The southerlies maximized just offshore rather than over the terrain slope as one would expect from trapped flow. Thus, coastal trapping would not appear to be a necessary condition for eddy formation. This conclusion differs substantially from that of Ulrickson et al. (1995), who performed a simulation in which the coastal mountains south of the bight region were removed and an eddy did not result. The difference in results hinges on the fact that removal of terrain results in a different background state. For a given amount of vorticity generation, a state with stagnation over the bight region more easily allows an isolated eddy than a state with strong onshore flow, as results when the mountains along the southern California coast are removed.

The sea breeze has been considered the main diurnal effect modulating the Catalina Eddy intensity (Bosart 1983, Wakimoto 1986). We find here that the sea breeze is relatively inconsequential because the simulation ND00 produced the strongest eddy of any simulation (Fig. 2). The diurnal cycle has also been noted to favor enhanced vorticity at night over the bight region (Ueyoshi and Roads 1993), but the cause of this has not been explained. The important effect of the diurnal cycle is to modulate the strength of the coastal jet impinging on the mountains, and hence the downstream response. During the morning, the low-level flow approaching the San Rafael Mountains from the north is nearly zero but in the evening this flow strengthens to about 10-15 m/s. The enhanced low-level flow implies enhanced lee subsidence, which depresses the marine inversion further, creating a stronger warm anomaly and cyclonic vortex.

It appears that there is an optimal flow strength for generating a quasi-steady disturbance in the bight. If the low-level flow is too weak (as during the morning) there is no interaction with the terrain. The flow has difficulty ascending the mountain and the time-scale for the response is too long compared with the diurnal cycle. If the flow is too strong (as is the case prior to 30 June) then vorticity once produced will simply be advected away. Another way of stating the response is that there is an optimal Rossby number regime $U/fL < 1$, but not too small,which elicits the best mesoscale response on the time scale of half the diurnal period

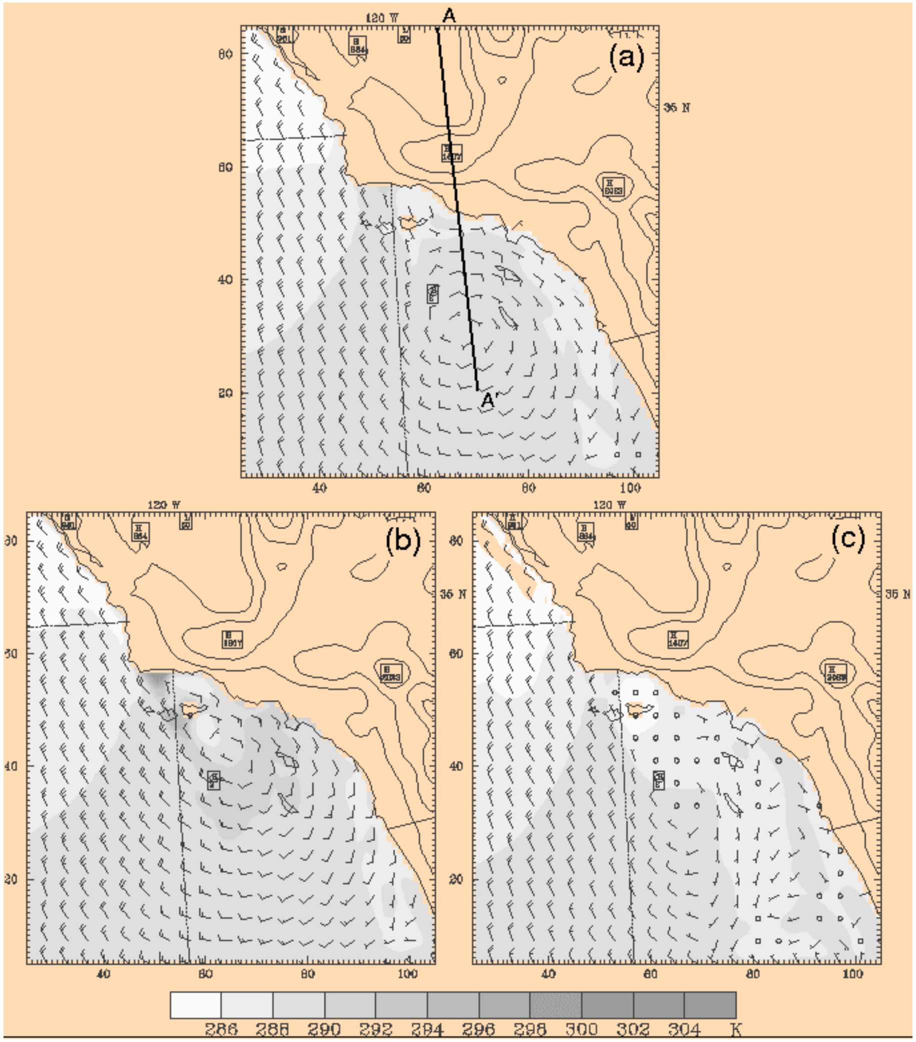

Figure 2. Wind and potential temperature (grey-scale) at 50 m MSL for (a) control simulation; (b) ND00 and (c) ND12 at 1200 UTC 30 June. Terrain is contoured in 400 m increments.

IMPACT:

This work represents a strong conceptual linkage between theoretical studies of moderate Rossby number flow interacting with orography and studies of observed phenomena within the coastal zone. In some cases, our conclusions depart significantly from those published by other investigators. We have placed full emphasis on the formation of vorticity within the coastal zone, which is the physical link between the large-scale flow and most coastally trapped disturbances.

TRANSITIONS:

RELATED PROJECTS:

This project has benefited from collaboration with Professor Clifford Mass at the University of Washington and Drs. Richard Rotunno, Joseph Klemp and William Skamarock at NCAR.

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